A model study of precipitation and extreme precipitation using a weather phenomena based method

Ming Zhao
Geophysical Fluid Dynamics Laboratory
NOAA

NOAA-DOE Precipitation Processes and Predictability Workshop
Nov. 30 – Dec. 2, 2020

Motivation

- At ~50km resolution, GFDL GCMs have been demonstrated to simulate reasonably well the climatology and variability of atmospheric rivers (AR, Zhao 2020), tropical cyclones (TC, Zhao et. al 2009) and mesoscale convection systems (MCS, Dong et. al 2020). Thus, they may be useful for studying precipitation and its extremes in the context of weather and climate connections.

- How much of the modeled present-day climatological precipitation and extreme precipitation may be attributed to AR, TC, and MCS?

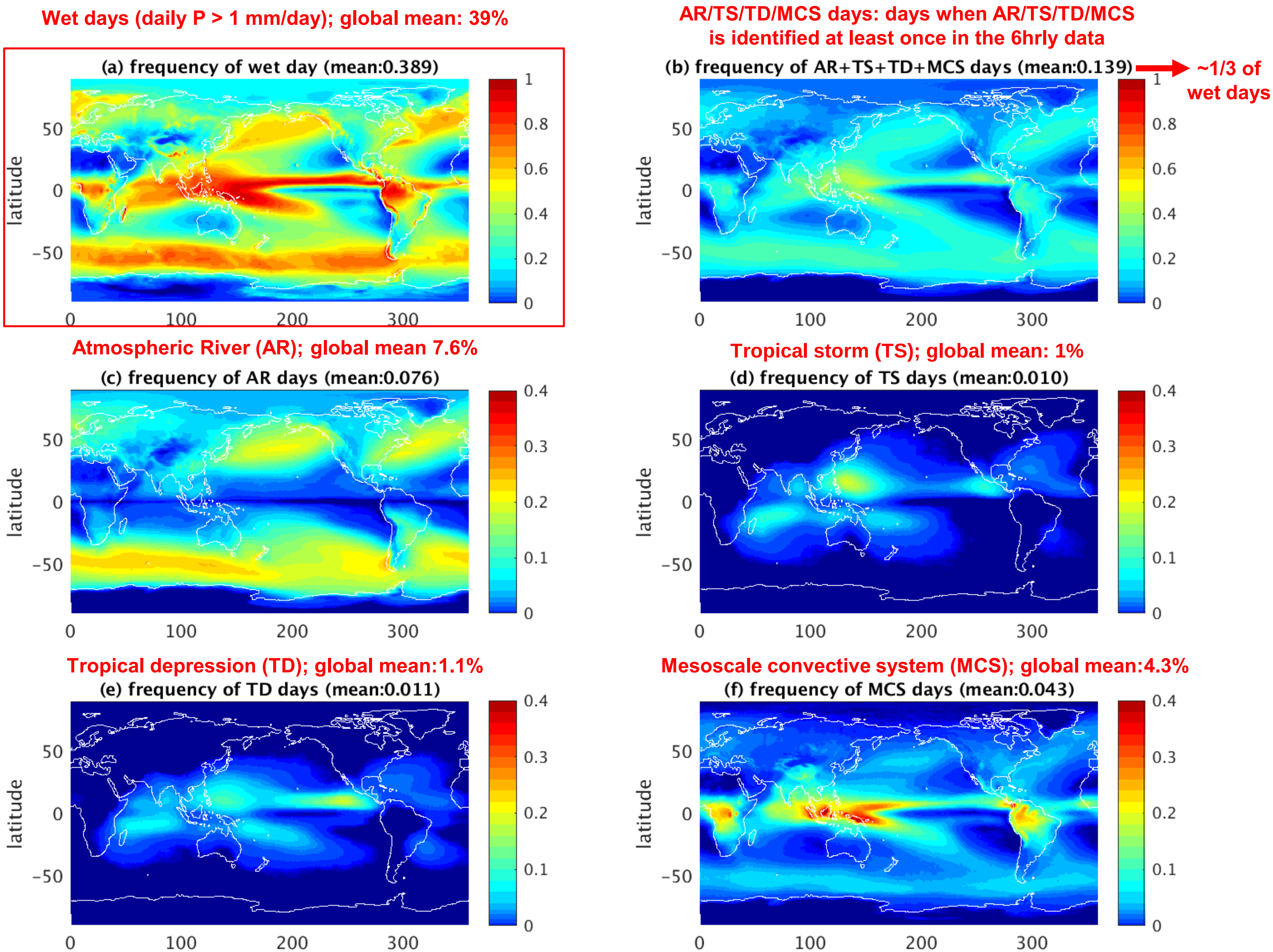
- How may precipitation and its extremes associated with AR, TC, and MCS change in a warmer climate? Why?

- How may we use observations to investigate model biases associated with AR, TC, MCS and their implications to future predictions?

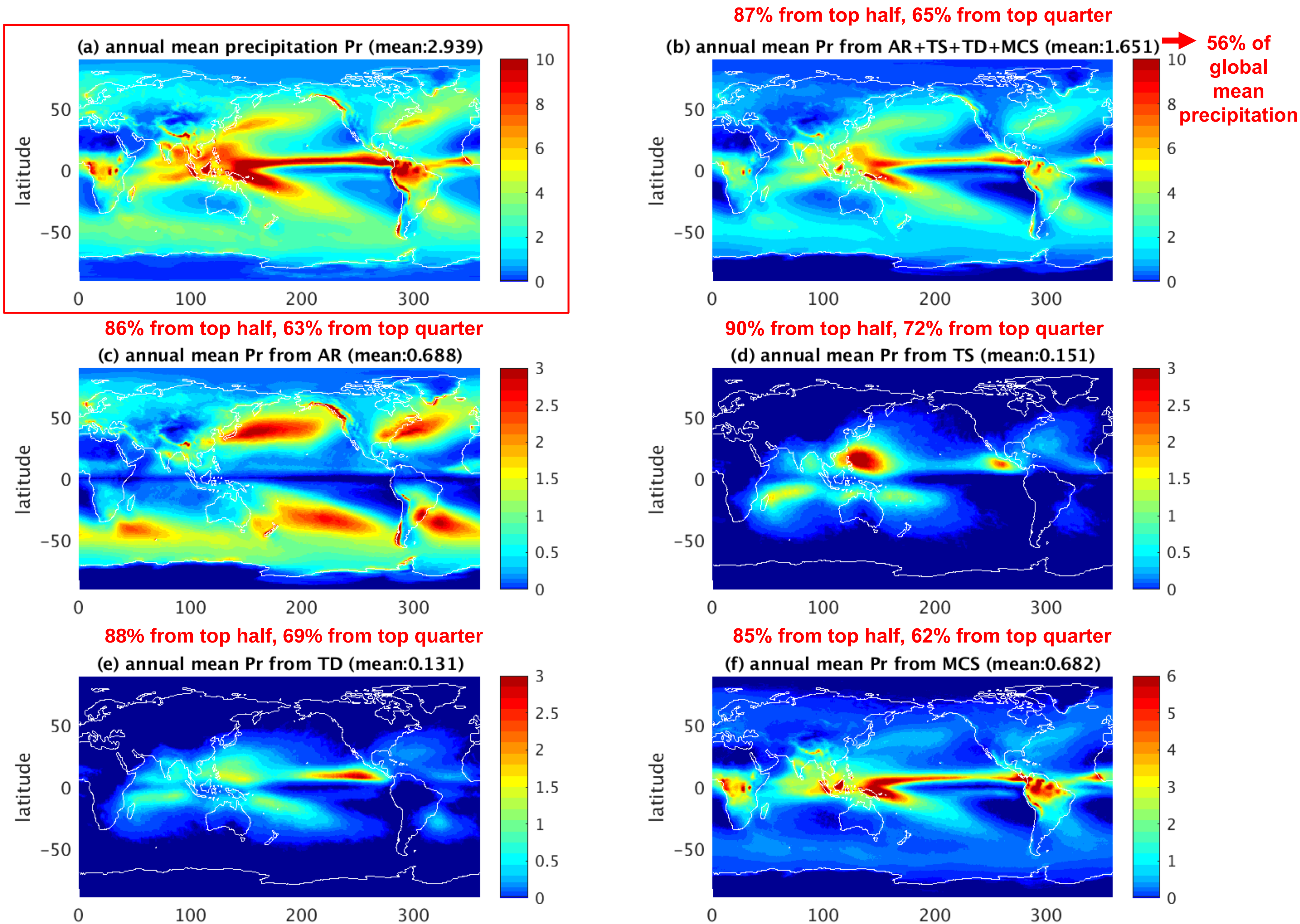
Model, simulation and detection method

- **C192 AM4 (Zhao et. al 2018ab, Zhao 2020):**
  - AM4 is the atmospheric model used in GFDL's new CM4 (Held et. al 2019), ESM4 (Dunne et. al 2020), and prediction system SPEAR (Delworth et. al 2019).
  - C192AM4 is AM4 running at a moderately high (50km) resolution and it is used for GFDL's participation in CMIP6 HighResMIP experiments.
- **Simulations:**
  - Control: 100-yr simulations with climatological SST/sea-ice, 2010 radiation
  - P4K: As control except SST uniformed increased by 4K
- **AR TC and MCS detection methods:**
  - AR: Guan and Waliser (2015), IVT based method used in Zhao (2020)
  - TC (TS/TD): Zhao et. al 2009 (TC intensity weaker than TS is considered as TD)
  - MCS: Dong et. al 2020 (OLR/BT+size, OLR<148 & OLR-$\mathrm{OLR_c} < 50\mathrm{W/m2}$)
- **Data:**
  - AR: 6-hrly IVT and its zonal and meridional component
  - TC (TS/TD): 6-hrly 850 vorticity, surface wind, sea level pressure, 300-500hPa T
  - MCS: 6-hrly OLR
  - Precip: daily mean precipitation from each AR, TS/TD (6° from center), MCS

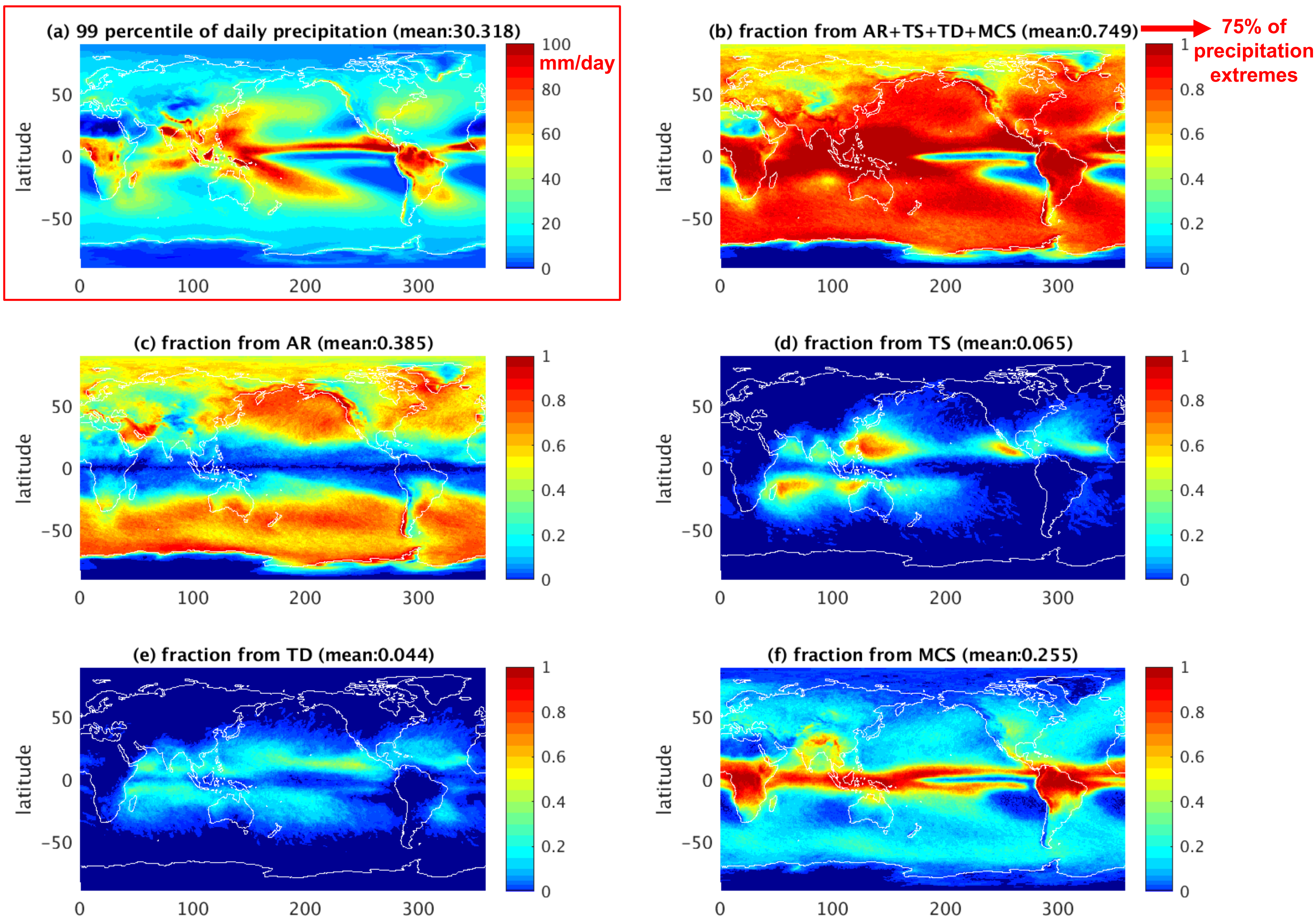
Geographical distribution of the annual frequency of wet, AR, TS, TD, and MCS days



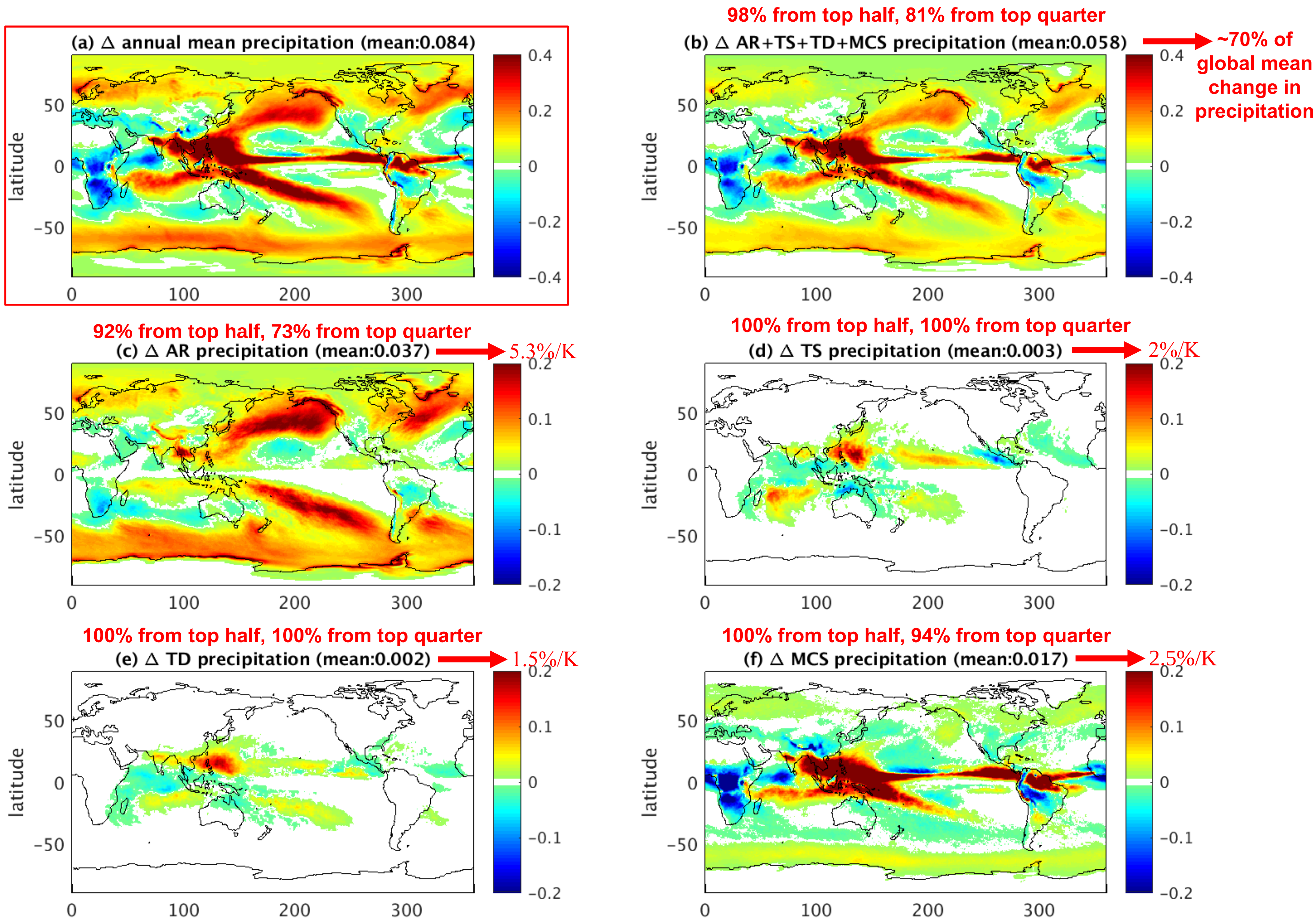
Annual mean precipitation and its contributions from the AR, TS, TD, and MCS days (mm/day)



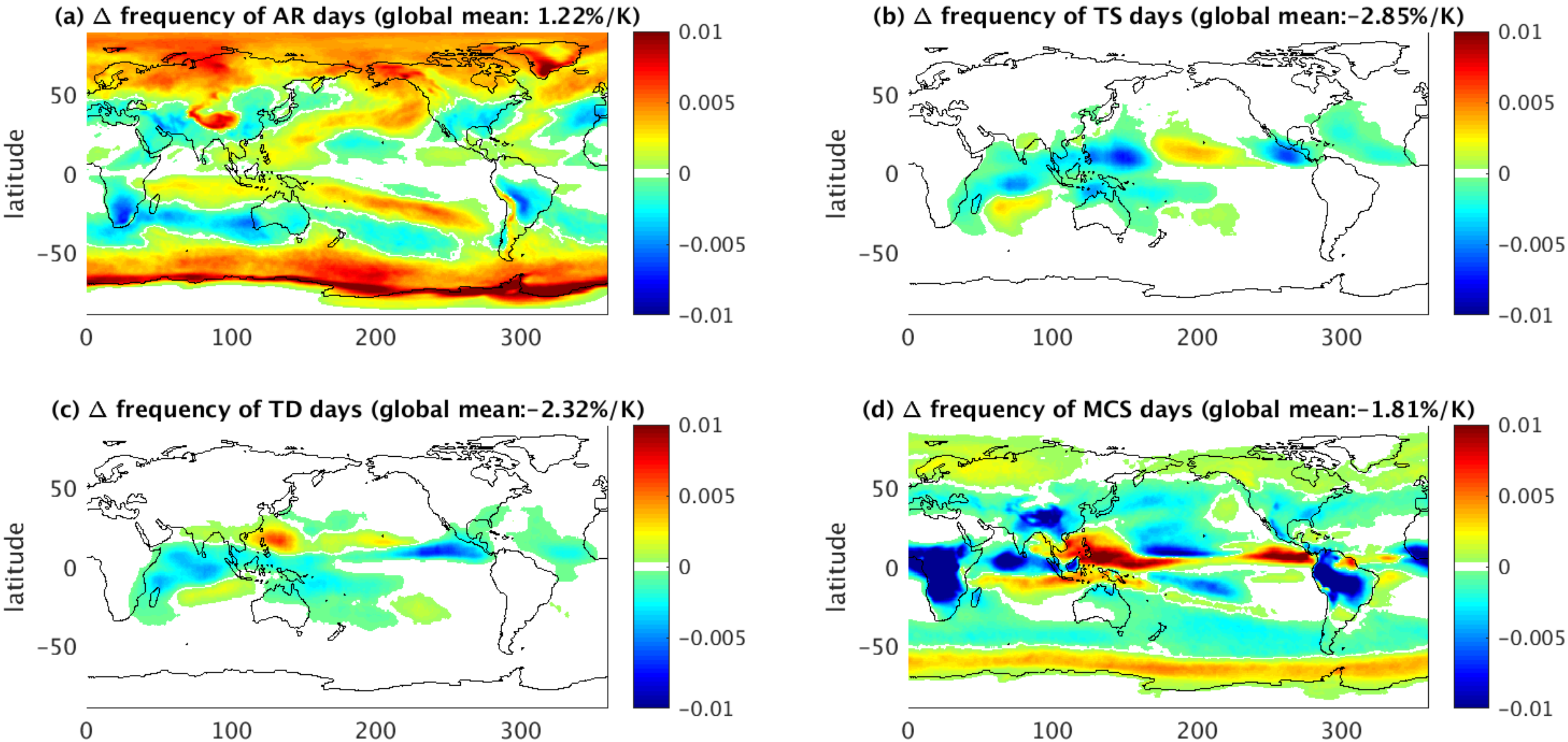
99 percentile of daily precipitation (P99) and the frequency of extreme precipitation with daily rate > P99 from AR, TS, TD, and MCS days



Change in annual mean precipitation with global warming and its contributions from AR, TS, TD, and MCS days (unit: mm/day/K)

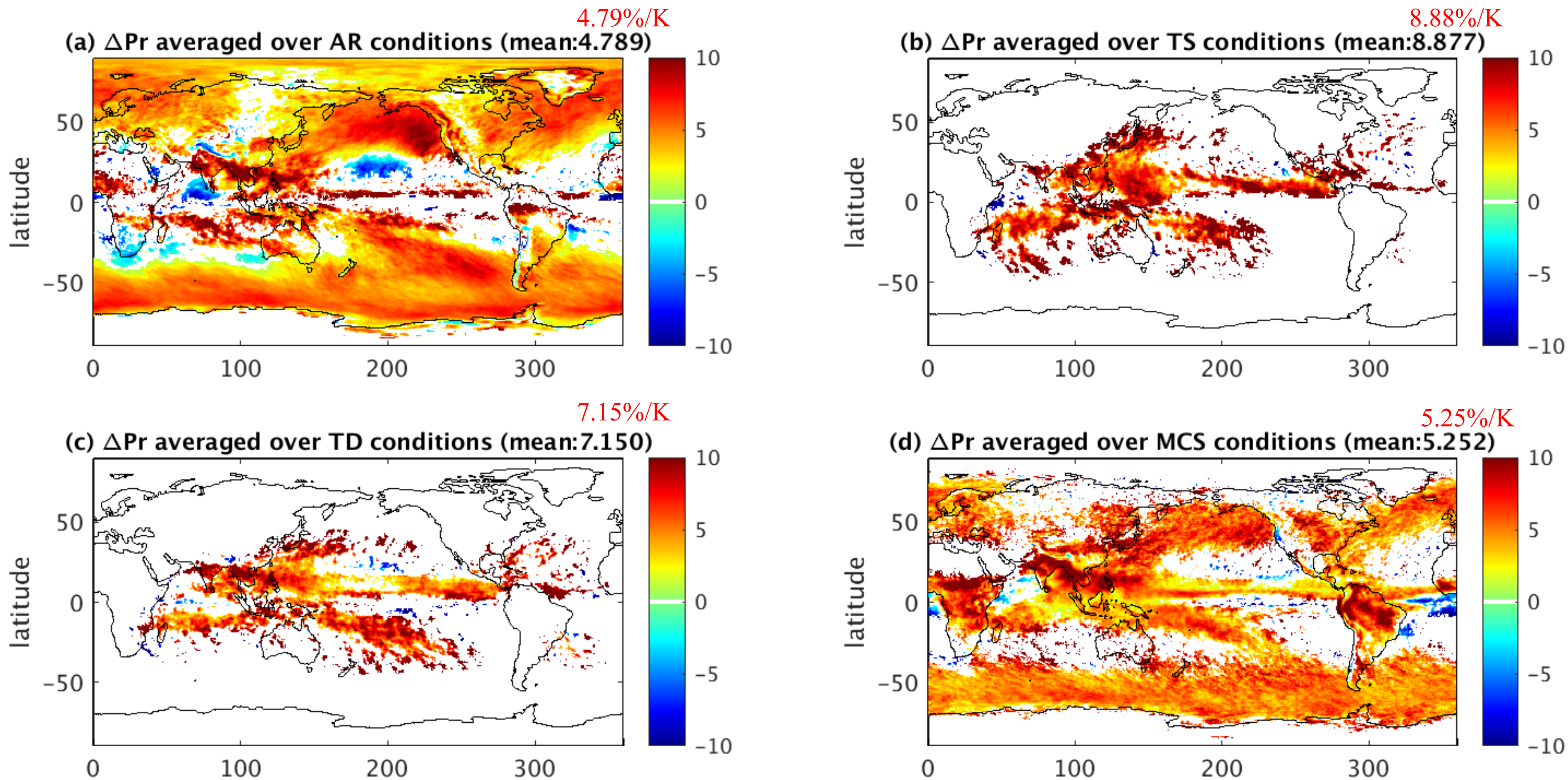


Change in the frequency of AR, TS, TD, and MCS days with global warming (unit: K^{-1})



Unit: change in frequency per 1-degree global mean warming

Percentage changes in daily precipitation rate averaged over the AR, TS, TD, and MCS days (unit: %/K)



$$P_e = -\epsilon \int \omega \frac{\partial q_s}{\partial p} \frac{dp}{g}$$

Muller et. al 2011

$$\frac{\delta P_e}{P_e} = \frac{\partial \epsilon}{\epsilon} + \frac{\int \delta\omega \frac{\partial q_s}{\partial p} \frac{dp}{g}}{\int \omega \frac{\partial q_s}{\partial p} \frac{dp}{g}} + \frac{\int \omega\, \delta\left(\frac{\partial q_s}{\partial p}\right) \frac{dp}{g}}{\int \omega \frac{\partial q_s}{\partial p} \frac{dp}{g}}$$

microphysic **dynamic** **thermodynamic**

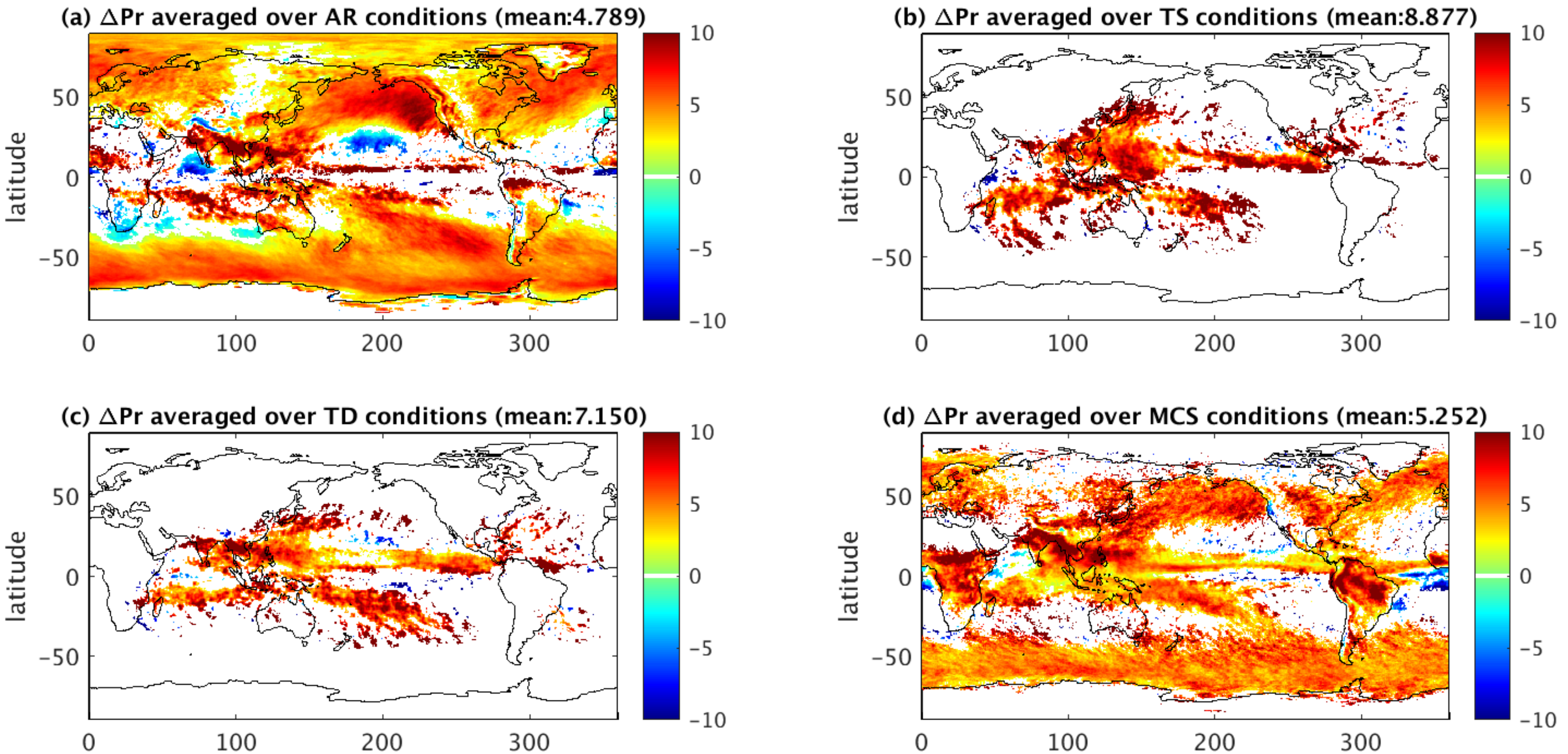
Weather regime based analysis may be useful for understanding not only precipitation response to warming but also the causes of model biases from individual processes

Summary

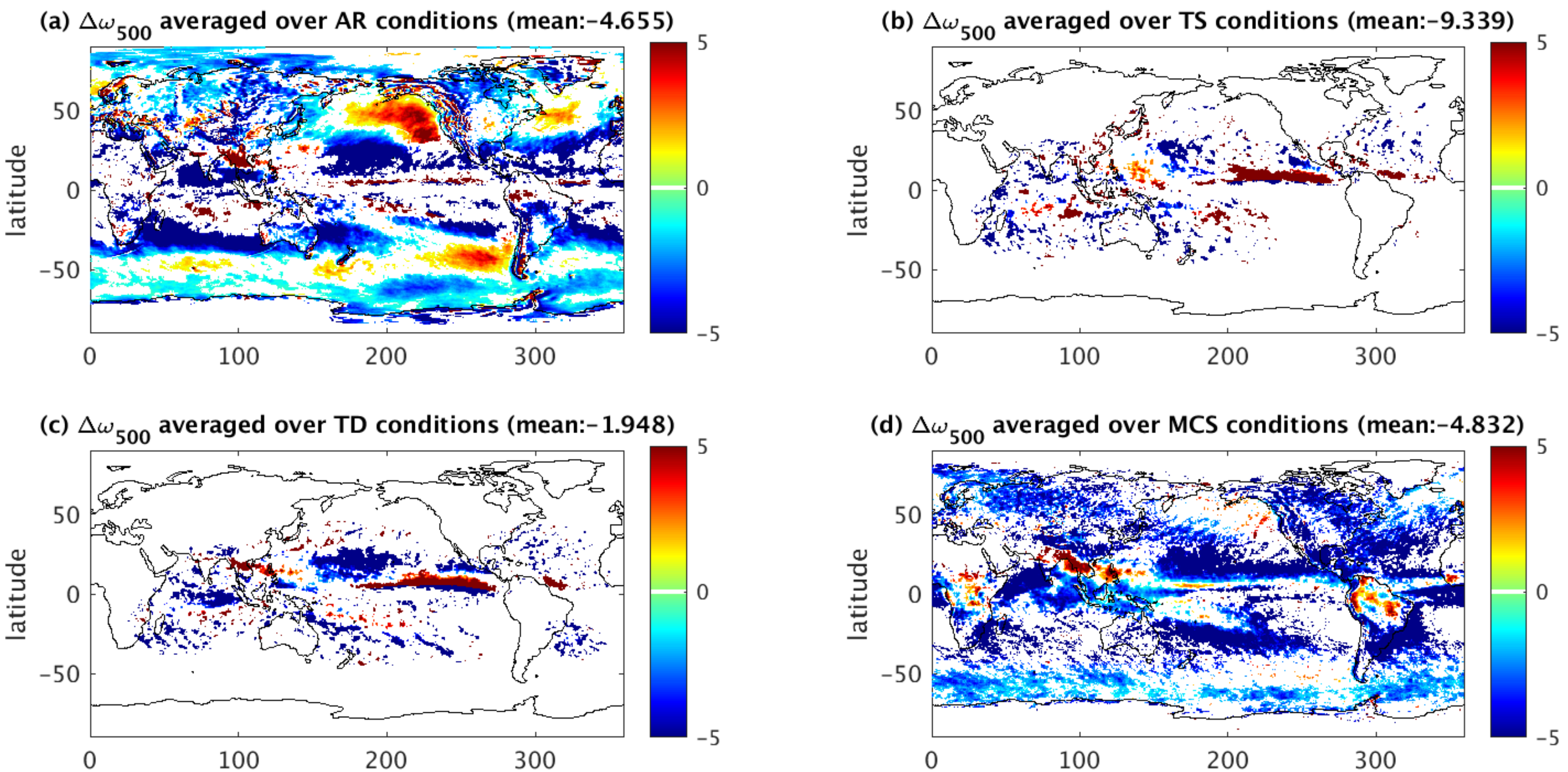
- The model results suggest that despite their occasional occurrence, AR, TC, and MCS together account for ~56% of global mean precipitation and ~75% of the extreme precipitation whose daily rate exceeding its 99 percentile. Regionally, they account for 80-100% of extreme precipitation in most parts of the world.
- Both the global mean and geographical distribution of the modeled changes in annual mean precipitation in response to global warming correspond well with the changes in precipitation associated with AR, TC and MCS days.
- Globally, the modeled frequency of AR days tends to increase slightly and migrate towards high latitudes while the frequency of TC and MCS days tends to decrease with large reduction of MCS over the tropical lands.
- The modeled precipitation averaged over the AR, TC, and MCS days increase by 5-10%/K roughly following the C-C scaling of water vapor. Most of the increase occur over their top 25% heaviest precipitation days. Changes in dynamics and microphysics appear to play secondary role in determining the response in extreme precipitation in a warmer climate.
- Precipitation analysis based on weather regimes should be useful for process-oriented model diagnostics/evaluation/improvement.

End

Changes in precipitaiton averaged over all AR/TS/TD/MCS days



Changes in ω_{500} averaged over all AR/TS/TD/MCS days



Changes in precipitable water averaged over all AR/TC/MCS days